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A Variable Capacitor

Wide-spaced variable capacitors, suitable for high-power ATUs and similar applications, are expensive and difficult to source nowadays. Hamish Storie MM0GWO explains how to roll your own.

I have been considering building a new ATU (Antenna Tuner Unit) because my current one limits me to about 60W having been constructed using general purpose receiver variable capacitors. Attempts at higher power usually result in arcing across the plates.

Suitable variable capacitors needed to be capable of handling greater than1kV, which required spacing in the order of 1mm or more between the plates, and to have a capacitance in the region of 350pF. Such capacitors are expensive, if you can even find them in the UK, so I turned my thoughts to constructing a capacitor from scratch.

Design Considerations

There were various things I needed to consider such as what materials to use, how to mount the static (stator) and moving (rotor) plates, how to make electrical connections to the plates and, more fundamentally, the size and number of plates required. I rapidly concluded that the first model would be very experimental and the result is shown in **Fig. 1**.

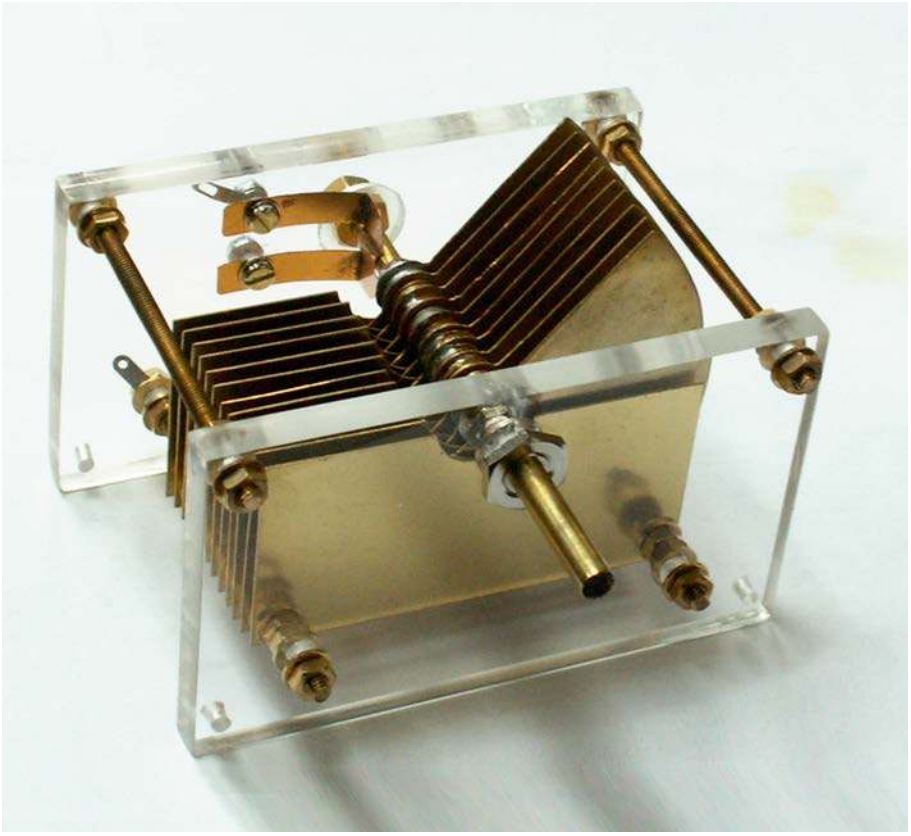

Fig. 1: The first, experimental, attempt at building my own variable capacitor.

Size and Number of Plates

The capacitance of a variable capacitor depends upon the size and number of plates, the dielectric (in this case air, which can be ignored) and the distance between the plates. After re-running the following calculation a few times and experimenting with the plate spacing, I settled on the dimensions shown in **Figs. 2a** and **2b**, with ten moveable plates, 11 fixed plates and an air gap of about 1.3mm between the fixed and moveable plates.

The equation for a capacitor with an air dielectric is:

$C = E_o \times A/d$ where:
C is the capacitance in Farads.
E_o is the permittivity of free space, 8.85×10^{-12} Farads per metre.
A is the area of the plate overlap in square metres.

Assuming that the moveable plates are approximate half circles and that there is a fixed plate on either side of each moveable plate, the total area of plate overlap will be approximately 2 × the half circle area × number of moveable plates.
A is therefore $2 \times ½ \times 3.14 \times \text{radius}^2 \times$ number of moveable plates.
d is the distance between the plates in metres.

The area of plate overlap for a 40 mm radius semi-circular plate with an air gap of 1.3mm gives an expected capacity in the order of:
$C = 8.85 \times 10^{-12} \times .14 \times (40 \times 10^{-3})^2 \times 10/1.3 \times 10^{-3}$
C = 342 pF

Front and Rear Panels

The front and rear panels were made from 10mm Perspex sheet, cut and drilled as shown in **Figs. 3a** and **3b**. Having cut the Perspex, the edges were filed, then sanded to remove the saw marks. The final sanding was with very fine wet and dry paper to achieve a near polish. This can also be done with a cloth disc on a grinder, or similar, but care needs to be taken to avoid melting the surface being polished. The purpose of the 4mm holes should be clear from Fig. 1. However, the others will benefit from further explanation. Taking Fig. 3a first, the two 3mm holes at the foot of the panel are mounting holes, while the 9mm hole is drilled to accommodate a 6mm panel bush, which is the bearing for the capacitor shaft. The rear panel shown in Fig. 3b is very similar to that of Fig. 3a except that there are a further two 3mm holes, whose position is determined during construction, along with a slightly more complex arrangement to accommodate the capacitor shaft. There is a 6mm hole drilled through the panel and that is

enlarged to 15mm to a depth of 5mm to accommodate the rear shaft bearing. This can be seen in **Fig. 4** and is explained in more detail later. A point worth noting here, for anyone planning on reproducing a similar capacitor, is that any deviation from the vertical becomes quite significant when drilling the 10mm Perspex and may require some holes to be opened out.

Stators and Rotors

I eventually decided to make the capacitor plates from 0.5mm brass sheet. My original plan was to use 1mm brass sheet. However, that turned out to be too heavy and also more difficult to cut. The rotor plates needed soldered and I did consider making them from tin plate, aluminium and single-sided printed circuit board. They were all discounted for different reasons although I believe that any of them could have been made to work.

Producing ten identical rotor plates and 11 identical stator plates was probably the most challenging part of the whole exercise. The measurements needed to be as accurate as possible, so my first thought was to pass the drawings of Fig. 2 to one of the laser metal cutting companies for a quote. I may go down this route in the future if constructing a few capacitors but for the small quantity of plates needed, it was turning out to be a comparable price to purchasing an off-the-shelf capacitor. Having decided to cut my own plates, I set about preparing for the task. I used a spirit-based felt tip pen as a marking dye prior to scribing the metal before cutting and a magnifying desk lamp to assist in the marking of the metal. One of each of the plates was marked and cut out and these were subsequently used as templates for the remainder of the plates. Cutting the brass plate required the use of a tool such as a sheet metal nibbler or similar, which will remove a thin section of material without deforming the sheet. Tin snips or shears, like scissors, will always deform at least one side of the cut, if not both. The nibbler that I have removes a 1mm strip of material.

Cutting the Plates

I cut the stators in pairs, 1mm apart, with the semi-circular cut-out in each stator facing each other to form an (approximate) circle. That way, a 15mm hole can be made in the centre of the pair before separating them with the nibbler. This gave a near perfect semi-circular cut-out (only offset by 0.5mm). In this case the template was in the form of the edge-to-edge plates before separation, including a small pilot hole where the larger 15mm hole was due to be drilled. If a 15mm drill bit isn't available, a smaller hole can be carefully enlarged with a rat tail file. However, this should be done later when all the plates are being tidied up. The template also included pilot holes for the two 4mm mounting holes. The rotor plates were also cut out to my calculated dimensions, again including a pilot hole for the 4mm shaft.

Tidying Up

The two sets of plates were now available to tidy up. They were both checked for symmetry by reversing one and comparing it to another of the same type. The stators were 'squared up' by bolting them together using the pilot holes, clamping in a vice and carefully filing the surfaces flush. This would also be an appropriate time to enlarge the 15mm semi-circle if required. I used a similar technique on the rotor plates but, in addition, by distributing the various plates in a circle around a screw through the pilot hole, the whole assembly was mounted on the screw in a cordless drill chuck and turned while being run against abrasive paper to round off the plates.

Rotor Assembly

The whole rotor was built around 4mm threaded brass rod, with brass nuts and washers and can be seen in the photo, **Fig. 5**. Firstly, I located a single 4mm nut about 40mm down the rod. This was followed by a 4mm washer, which formed the bearing surface against the panel bush, while the end of the rod was taken up to 6mm diameter by inserting it into a section of 5mm brass tube. I then inserted this into the same length of 6mm tube. The nut, washer and tube are indicated on Fig. 5 as C, B and A respectively. Having established that these parts fitted together and ran smoothly with the panel bush, I then cleaned them thoroughly and soldered them together, taking care not to run solder over the face of the washer, which would be the bearing surface. Firstly, another nut, which was to be an adjustable spacer, was screwed up the threaded rod up to the recently soldered nut. The rotor plates were then added as follows (D in Fig. 5): a single washer followed by a plate, followed by four washers, followed by a plate, followed by four washers and so on. The final plate was then followed by a washer and a nut to secure all the plates.

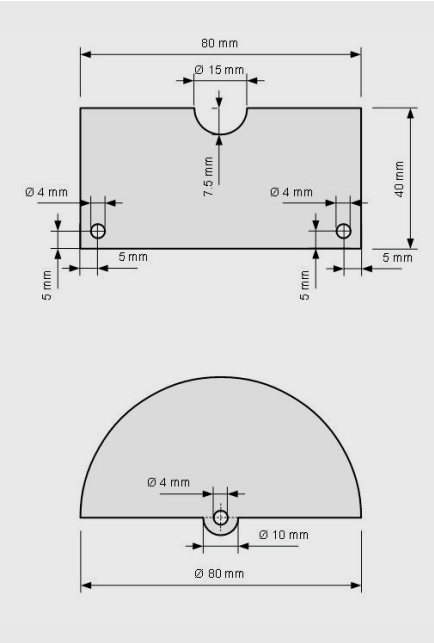

Fig. 2: Calculated dimensions for (a) fixed and (b) moving

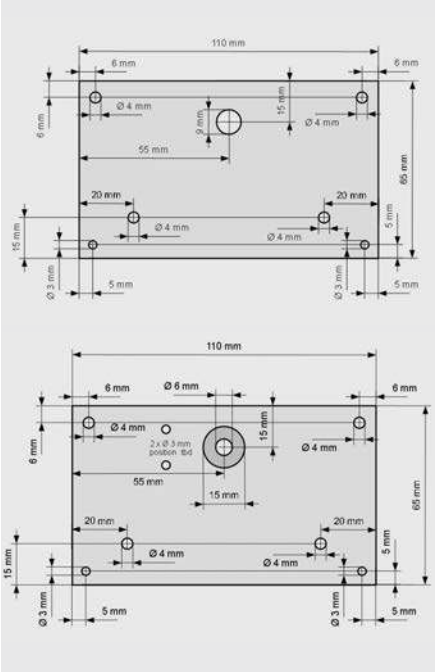

Fig. 3: Dimensions for (a) front and (b) rear Perspex panels.

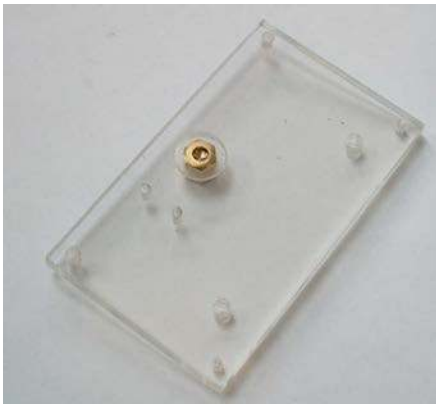

Fig. 4: The rear panel, showing the hole for the shaft.

These would eventually be soldered, but not at this point.

Stator Assembly

I assembled the stator plates in a similar manner to the rotor plates using two sections of brass rod and spacing them with four washers between each plate. Nuts were added at either end, leaving enough rod to secure the assembly to the Perspex ends. Having assembled both sets of plates, they were loosely fitted to the front end plate and the capacitance checked.

I made the rear bearing from 5mm brass tube and a M6 brass set screw with a 5mm hole drilled into its hex head to about half the head depth as shown in Fig. 4. To make a smooth-running bearing, the end of the tube needed to be reduced very slightly in diameter and this was achieved by clamping it in a cordless drill chuck and turning it against wet and dry paper. Having made the smooth bearing, the tube was cut down to 15mm and placed on the end of the threaded rod (E on Fig. 5), which had been cut down to fit.

A further nut was put onto both ends of each rod, before the Perspex end plates, to act as adjustable spacers, then a temporary assembly undertaken to make sure that it all fitted together. The end plates were fitted, the moving parts checked for smooth operation and acceptable spacing between the plates was confirmed. Having established that all was well, I disassembled the rotor, then cleaned and reassembled it ready for soldering. I didn't consider it necessary to solder the stator plates because the assembly was sturdy enough. A small gas blowlamp was used and a minimum quantity of solder was applied to all the joints of the rotor and the rear bearing. I took care to ensure that solder didn't run down the surface of the individual plates. The soldering can be seen in Fig. 5.

Final Assembly

The capacitor was reassembled, checked again for smooth running and plate separation, then the excess threaded rod was trimmed off at each end.

All that remained were the electrical connections. The connection to the stator was straightforward and consisted of a solder tag on the end of a stator threaded rod. The connection to the rotor was made via a phosphor bronze spring in contact with the 5mm rear rotor bearing. This can be clearly seen in Fig. 1. To make the spring, 0.5mm phosphor bronze sheet

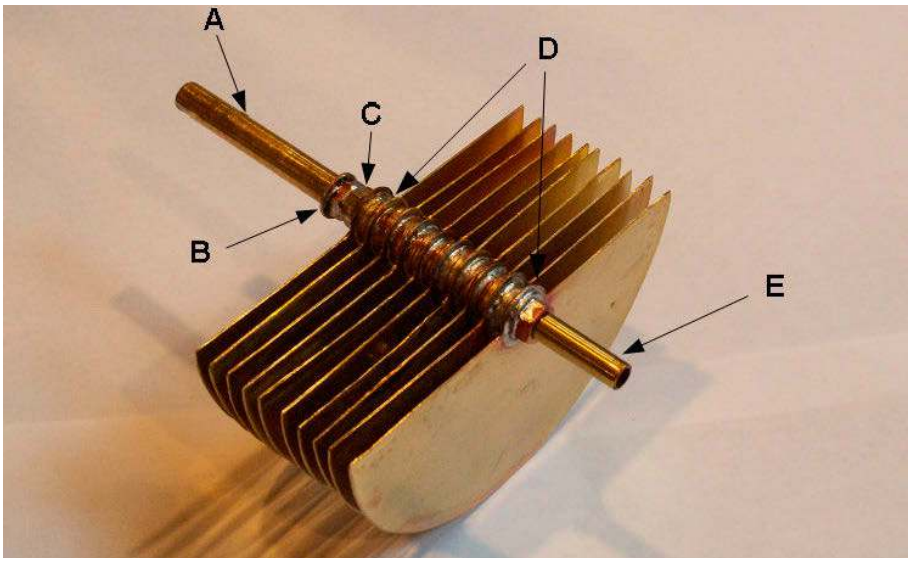

Fig. 5: The moving plate assembly.

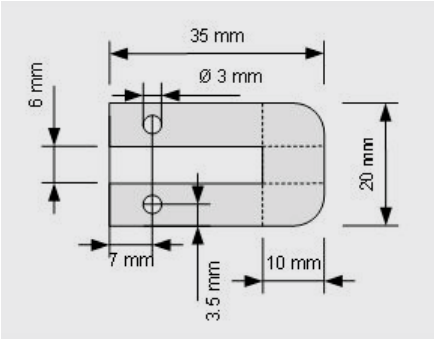

Fig. 6: Dimensions for the phosphor bronze contact spring.

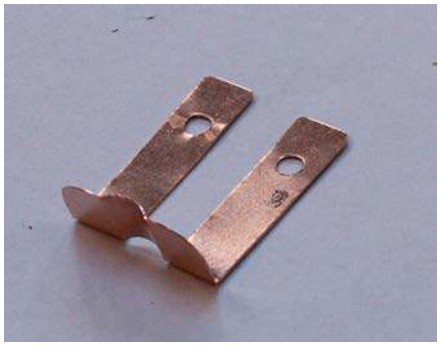

Fig. 7: The completed contact spring.

was cut to the dimensions shown in **Fig. 6**, bent along the dotted lines and then curved around the shaft of a 5mm drill bit to produce the final result in **Fig. 7**.

The rear plate of the capacitor was removed again and the phosphor bronze spring positioned in such a way that it was continuously pressing on the rear bearing, so making a good electrical contact. Having marked its position, the two remaining 3mm holes were drilled and the spring screwed in place with a solder tag on one of the fixings. The capacitor was then reassembled.

Conclusion

The method of construction really tested my metal marking and cutting skills but the finished product is a good solid working variable capacitor. My planned ATU requires a two-gang capacitor. This can be achieved by adding a further Perspex plate mounted centrally to support, and separate, a second set of stator plates. It would be equally easy to make a differential capacitor using the same technique and offsetting a second set of rotors or by increasing the end plate size and hanging a second set of stator plates 'upside down'.

Finally, considering the stray capacitances making up the minimum capacitance, the measured value of the capacitor came out almost exactly as anticipated. Using an Atlas LCR meter, the values were 17.8pF minimum and 366.8pF maximum.

Parts List

All the materials are available from the normal internet auction sites or, if preferred, a combination of electronics suppliers, model shops and engineering suppliers.

10mm Perspex sheet
0.5mm brass sheet
0.5mm phosphor bronze sheet
6mm panel bush
5mm brass tube
6mm brass tube
2 x 16mm M3 screws plus nuts and washers
M4 brass rod as required
M4 brass nuts as required
M4 brass washers as required
1 x 16mm M6 brass set screw and nut
Solder tags